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Fast-writing E-beam for large arrays of nano-holes

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Efficient nanoscale patterning of large areas is required for sub-wavelength optics. For example, 200 nm periodic structures are often too small to be made with standard UV- and DUV-equipment. Still, the final product must be made at an economic cost.
EBL writing time consists of shape time, beam time, stage time and calibration time.

Efficient nanoscale patterning of large areas is required for sub-wavelength optics. Here we use a fast-writing strategy described in [1], where electron beam lithography (EBL) with a focused Gaussian beam is used to define shapes directly. The serial technique is optimized for speed and pattern fidelity to a maximum writing speed of around 30 min/cm² for 200 nm periods in 2D lattices. The overall costs in terms of machine time and feasibility are assessed.

Single shot Exposure

Conventionally, EBL uses multiple exposures of slightly overlaying spots. Instead, the fast-writing strategy uses the machine as a raster scan tool to write a large rectangle, using a beam step size larger than the spot size [1,2].

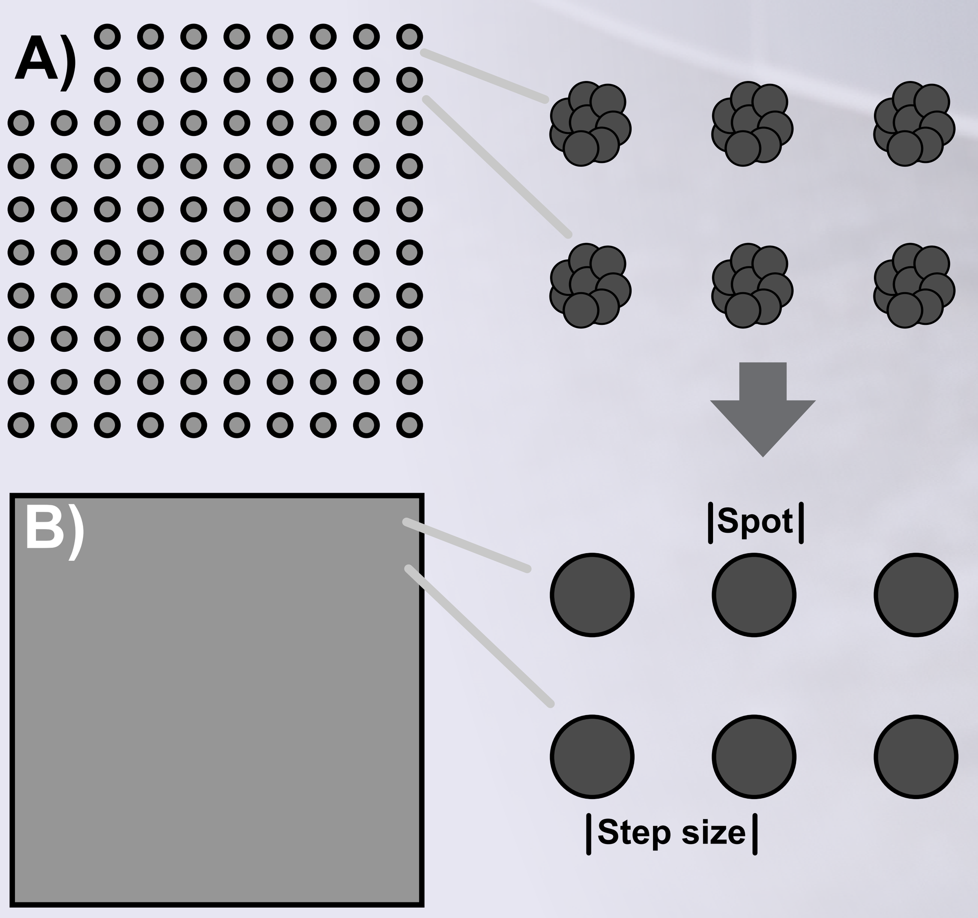

Figure 1. Illustration of the fast-writing exposure strategy. (A) The conventional method for pattern layout is to design an array of circular spots to form the final pattern. (B) Fast-writing patterns are formed directly by a single exposure with a given spot size spaced by the beam step size. Redrawn from [1].

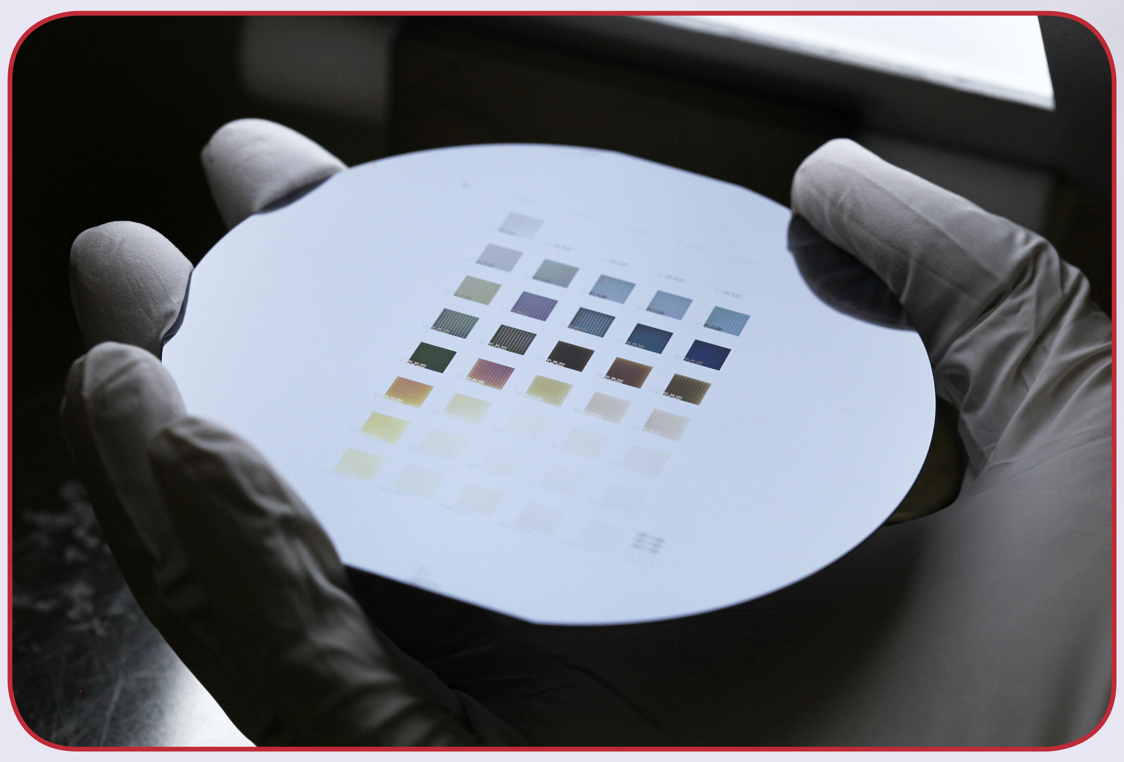

Figure 2. Photograph of writing time test areas of 5 mm x 5 mm. Photographer: Jesper Scheel, DTU.

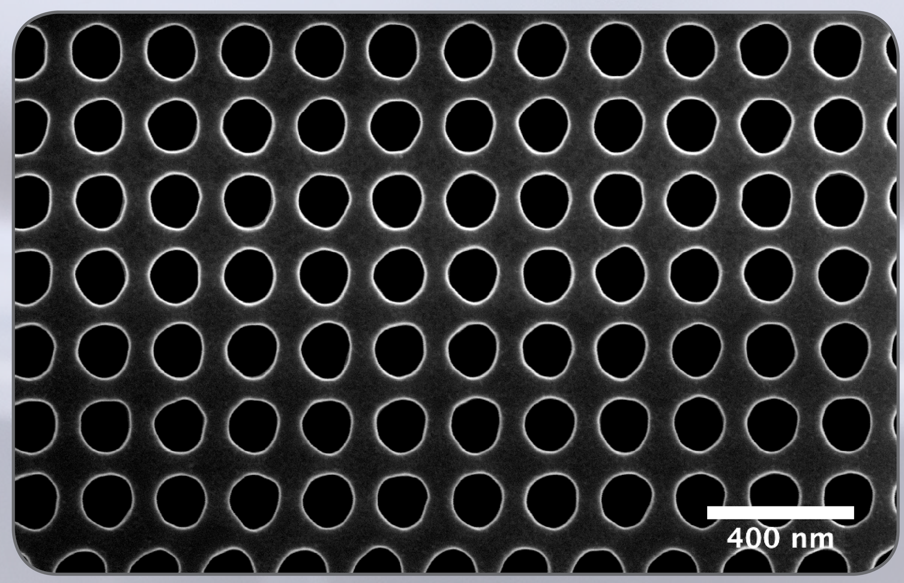

Figure 3. SEM micrograph of typical silicon structures with period 200 nm and dose 140 µC/cm².

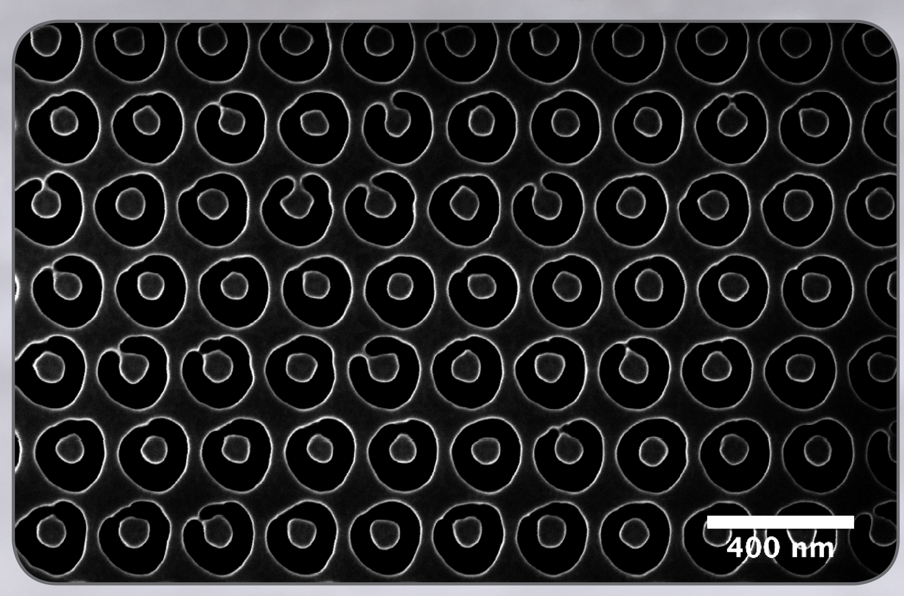

Figure 4. SEM micrograph of silicon structures illustrating non-square lattice and out-of-focus possibilities of structures with period 225 nm and dose 140 µC/cm².

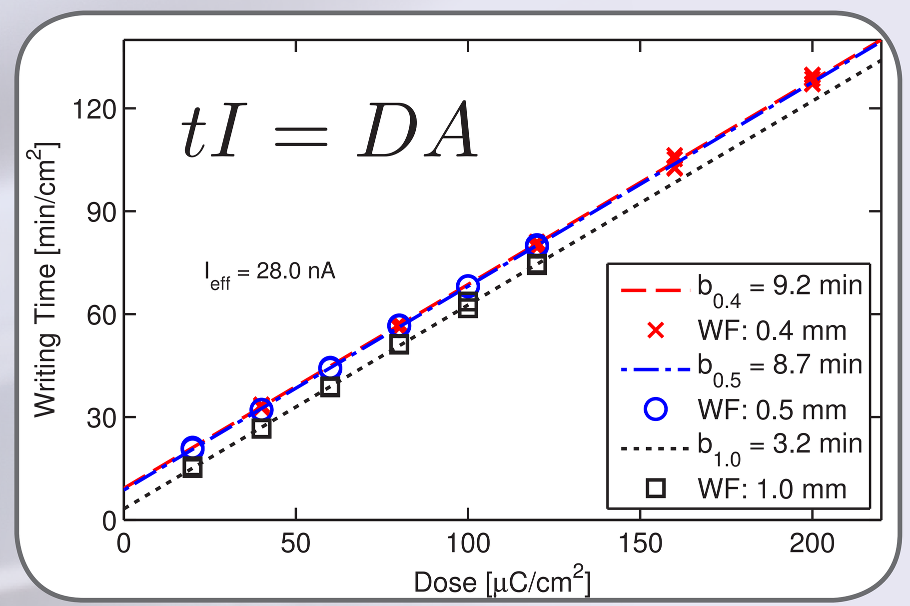

Figure 5. Measured writing time and linear fits as function of dose for different writing field side lengths with array periods in the range 150-250 nm. Y-axis b parameter. Exposure includes 5 min cyclic calibration. Initial machine calibration not included.

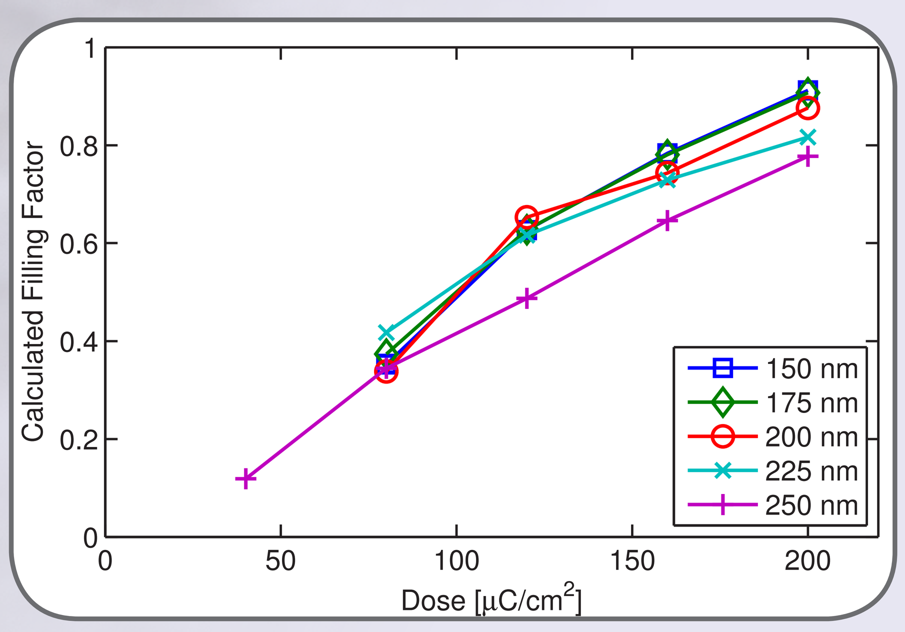

Figure 6. Filling factor as function of dose calculated by image analysis of SEM images similar to Fig. 3 and Fig. 4. Different periods are analyzed.

Validation and Experimental Results

The JEOL JBX-9500FS is a prototype EBL 100 keV system with electron-beam scaning speeds up to 100 MHz.
Writing time tests of exposing 5 mm x 5 mm can be seen in Fig. 5 as function of dose. The effective current, that is the inverse slope is 28.0 nA, including time for calibration etc. Writing times are below 2 h/cm² and even a writing time of around 30 min/cm² for 40 µC/cm² can be achieved.
Efficient calibration routines become imperative with this method.

$$f = \frac{I}{D\Lambda^2} = \frac{A}{t\Lambda^2}$$

Conclusion

An EBL writing time below two hours per cm² provides new possibilities where sub-wavelength structures can be used to provide functionality such as anti-reflective or plasmonic effects for large area applications in a cost-effective manner, similar to traditional parallel processing techniques.

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References

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